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Status of EPA's (Environmental Protection Agency's) LIMB (Limestone Injection Multistage Burner) Demonstration Program at Ohio Edison's Edgewater Unit 4

Babcock and Wilcox Co., Barberton, OH

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by

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Limestone	Flue Gases	Stationary Sources	08G	21B
Burners	Sorbents	Limestone Injection Multistage Burners (LIMB)	13A	11G
Coal			21D	
Sulfur Oxides			07B	
Nitrogen Oxides				

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STATUS OF EPA'S LIMB DEMONSTRATION PROGRAM

AT OHIO EDISON'S EDGEWATER UNIT 4

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ABSTRACT

The paper describes and discusses the key design features of the retrofit of EPA's Limestone Injection Multistage Burner (LIMB) system to an operating, wall-fired utility boiler at Ohio Edison's Edgewater Station. It further describes results of pertinent projects in EPA's LIMB program and shows how these results were used as the basis for the design of the system. The full-scale demonstration is expected to prove the effectiveness and cost of the LIMB concept for use on large-scale utility boilers. The equipment is now being installed at Edgewater with system start-up scheduled for May 1987.

This paper has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

INTRODUCTION

The U.S. Environmental Protection Agency is engaged in a research program to develop improved control technologies for emissions of sulfur and nitrogen oxides (SO_x and NO_x) from the combustion of fossil fuels. This issue is important because of the magnitude of these emissions and their apparent link to acid rain. The cause of acid rain and its potential solutions are still being debated; however, control of SO_x and NO_x from power plants is a major element in all proposed control strategies.

Control techniques for acid rain will likely include a combination of technologies to achieve the mandated pollutant reduction at a cost that will minimize the impact on the nation and on specific geographical areas. Analysis indicates that low capital cost technology for retrofit to existing boilers would provide flexibility in control strategy even at moderate (e.g., 50%) SO_2 removal rates. One such technology is LIMB (Limestone Injection Multistage Burner), which is based on the injection of dry sorbents into the boiler for direct capture of SO_2 from the combustion gases. LIMB combines sorbent injection for SO_x control with the use of low-NO_x burners, in which staged combustion is utilized for NO_x control.

WALL-FIRED LIMB DEMONSTRATION

The EPA Wall-Fired LIMB Demonstration is a 4-year project that includes design and installation of a LIMB system at the 105 MWe Unit 4 boiler at Ohio Edison's Edgewater Station in Lorain, Ohio. The project includes a full year of operating and testing to demonstrate LIMB's capabilities. EPA is sharing the cost of the project with the major project participants—the State of Ohio, Ohio Edison, and Babcock & Wilcox (B&W).

The basic goal of the LIMB Demonstration is to extend LIMB technology development to a full-scale application on a representative wall-fired utility boiler. The successful retrofit of LIMB to an existing boiler is expected to demonstrate that reductions of 50% or greater in SO_x and NO_x emissions can be achieved while maintaining boiler reliability, operability, and steam production.

Recently, the project has been expanded to include flue gas humidification as an adjunct technology to LIMB. Humidification is expected to improve utilization of the unused calcium component of the spent LIMB sorbent for downstream SO_2 removal at a low incremental cost and increase the overall SO_2 removal of the system to 60% or greater. Humidification of the flue gas will also result in improved ESP performance due to gas cooling and reduction in ash resistivity.

The Demonstration project consists of several distinct phases—a preliminary phase to develop the LIMB process design applicable to the host boiler, a construction and start-up phase, and an operating and evaluation phase—as shown on the project schedule (Figure 1). The development of the Edgewater LIMB design was completed in January 1986, and construction is now under way. Major boiler-related components were installed during a September 1986 boiler outage. The expected start-up date is May 1987.

LIMB DESIGN ISSUES

A primary reason for the interest in sorbent injection is that its equipment requirements are simpler than those for other control technologies. However, since sorbent injection is much more closely coupled with the boiler, it must be designed for specific boiler characteristics and for compatibility with existing operating conditions. A generalized LIMB process diagram, including the humidification addition, is shown in Figure 2.

A number of major issues have been identified as being critical to the design and operation of a successful LIMB system. These issues can be summarized as follows for the Edgewater design:

- Development of a fundamental understanding of reaction chemistry and kinetics to enable optimization of system conditions for maximum LIMB performance.
- Selection of a sorbent that is sufficiently reactive for the SO_2 removal objectives and which is or can be produced commercially at a reasonable cost.
- Characterization of the Edgewater boiler temperature and velocity profile to identify the conditions under which injection must take place.
- Design of an injection system that will disperse the sorbent into the boiler under the optimum reaction conditions.
- Selection of a burner that satisfies low-NO_x goals and is compatible with the physical dimensions and requirements of the Edgewater boiler.
- Design of a sorbent handling system that will reliably deliver an accurate amount of sorbent to the boiler.
- Evaluation and/or modification of the particulate control system to enable collection of the increased amount of ash.

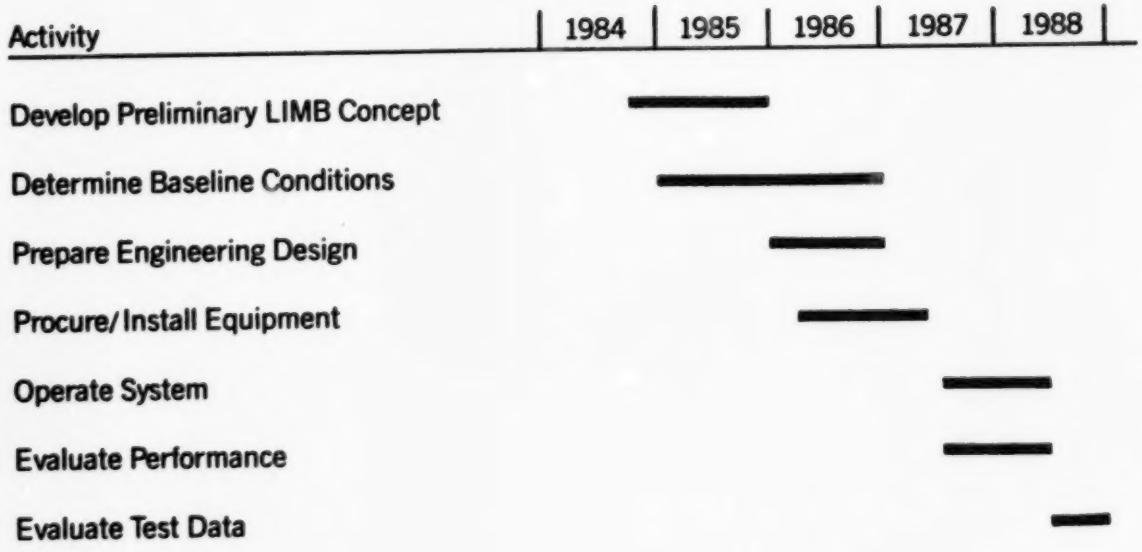

Figure 1. Project Schedule .

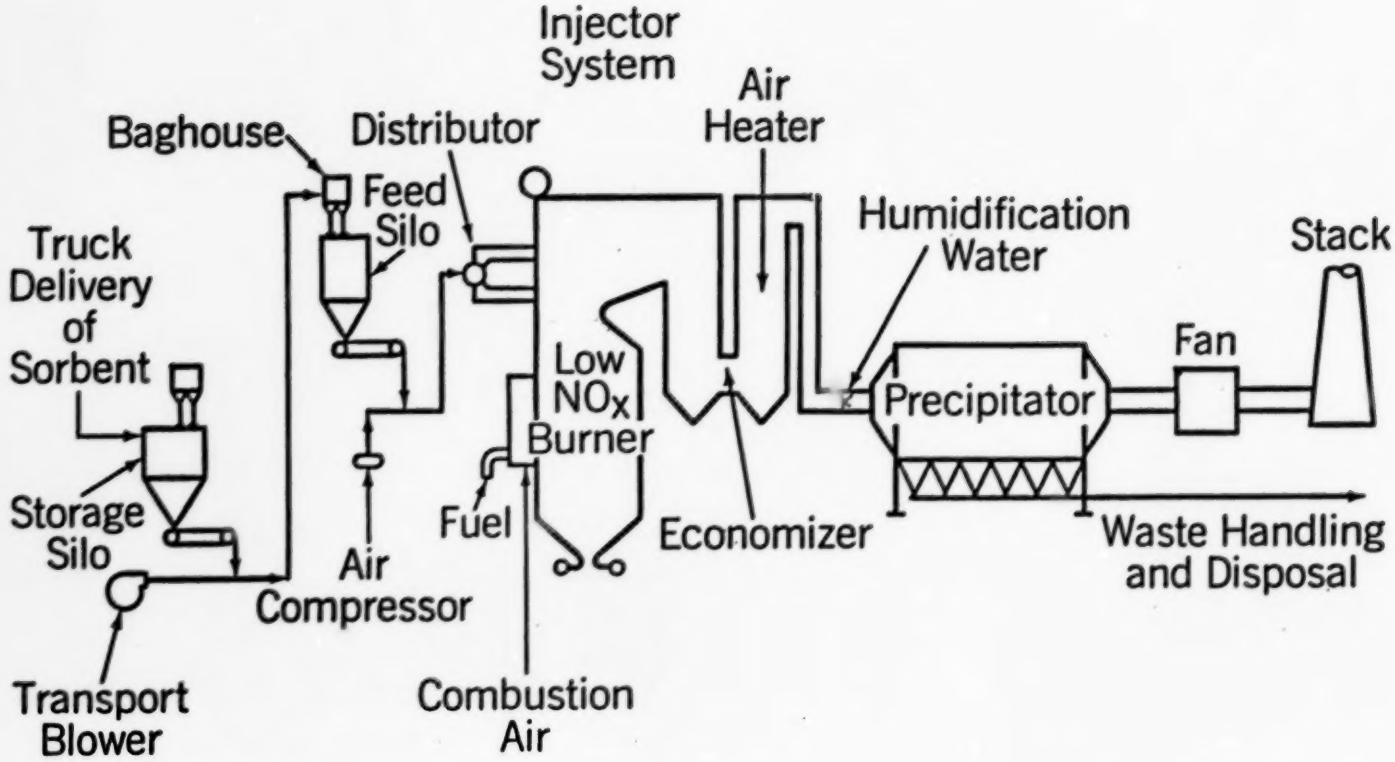

Figure 2. LIMB/Humidification Process Diagram.

- Design of an environmentally acceptable waste handling and disposal technique.

Each of these issues is being addressed in the EPA LIMB program, with recommendations for each issue being included in the Edgewater design.

FUNDAMENTAL CONSIDERATIONS

From a chemical process standpoint, sorbent injection is a complex technology that requires a reasonable understanding of the interrelationships among the various chemical and physical processes to enable design of a workable process. Several major reactions take place, the most important of which are calcination of the calcium sorbent to an active calcium oxide and sulfation of the calcium oxide with SO_2 in the flue gas to produce calcium sulfate. Sintering of the calcined material may also occur under certain conditions resulting in reduced reactivity. Rates and extent of reaction can be influenced by a number of factors, with each favored by some conditions and not by others. Research results have shown that achieving good sorbent reactivity and a high degree of sulfation is best in the temperature range of roughly 850° to 1250°C (1600° to 2300°F). Temperatures much above 1250°C (2300°F) result in sintering and deactivation via fly ash/sorbent interaction and fusion. Calcination and sulfation reaction rates are too low below 850°C (1600°F) to be viable. The sulfation reaction is also highly sensitive to residence time so that determining optimum injection location is a critical factor in the success of LIMB.

It was originally thought that sorbent could be injected through the burners; however, pilot combustion study results showed that burner injection is not as effective as downstream injection. The poor performance of burner injection is thought to be due to sintering and fly ash/sorbent interactions in this high temperature region. Further studies using pilot plant combustion systems have shown that the optimum injection point is at a point in the furnace where the combustion gas is approximately 1200° to 1250°C (2200° to 2300°F). In the Edgewater boiler, this point is in the upper furnace just above the furnace nose. Although offering the best temperature, this region experiences a very rapid decrease in gas temperature down to 850°C (1600°F) in the convective section. It becomes a special concern to design an injection system to achieve thorough mixing of the sorbent and combustion gases to enable reaction in the short residence time available.

SORBENT SELECTION

Selecting an appropriate sorbent and determining the type of preparation required to produce an optimum sorbent are vital to the technical and economic viability of sorbent injection. A wide range of calcium-based materials have been evaluated, varying in calcium form and content, content of magnesium and other materials, and type and degree of preparation.

In almost all cases during pilot combustion studies, hydrated lime [$Ca(OH_2)$] sorbents performed better than lime and raw limestone sorbents. A number of candidate calcitic hydrate sorbents produced within the general geographical area of the Edgewater plant have been evaluated under combustion conditions. The results showed that there was little difference in the reactivity of the candidate sorbents. However, these and other tests indicate that the smaller (<5 m) particles separated from a typical size distribution range of a commercial sorbent sample tend to be more reactive than larger particles of the same sample. This has been attributed to the avoidance of pore diffusion resistance of SO_2 into the particle. Further work has shown that a number of sorbent production alternatives favor generation of smaller particle size sorbents. Preliminary studies have shown that addition of certain surfactants or dispersants to the sorbent during hydration is beneficial to capture of SO_2. These surfactants are thought to minimize agglomeration of $Ca(OH)_2$ particles with each other and reduce the number of larger particles. Further studies are being conducted to evaluate the potential for using an enhanced hydrate as the demonstration sorbent.

BOILER CHARACTERIZATION

Due to the critical importance of boiler temperature and velocity profile on sorbent reactivity and sorbent mixing with combustion gases, a considerable effort was undertaken to characterize the Edgewater boiler. The work included flow characterization in a 1:15 scale acrylic model of the boiler, use of a computational boiler code to estimate temperature profiles, and direct measurement of temperature and velocity at selected points in the boiler.

Compilation and evaluation of this information show important implications for sorbent injection. The temperature zone of highest reactivity is located in the upper furnace from a plane just above the nose to a plane farther back in the convective section (Figure 3). A reduction in boiler load simply moves this zone closer to the boiler nose. Bubble streak flow visualization in the scale model showed that flow velocity increases near the nose, as would be expected, and that the flow is nearly uniform across the width of the boiler. Injection will take place at the plane of the nose in the high velocity region with sufficient injection velocity to penetrate and distribute the sorbent within the furnace. The residence time in the optimum temperature window is very short, on the order of 1 second, indicating that this boiler will be a rigorous test for sorbent injection.

SORBENT INJECTION

The design of an effective sorbent injection sytem will ensure rapid dispersion at approximately 1250°C (2300°F) for maximum reactivity and maximum time in the reaction zone. While considerable progress has been made in predicting penetration and distribution patterns for various injection schemes, the relationship between sorbent distribution and sulfur capture is less predictable. Based on present understanding, development of an optimum injector design

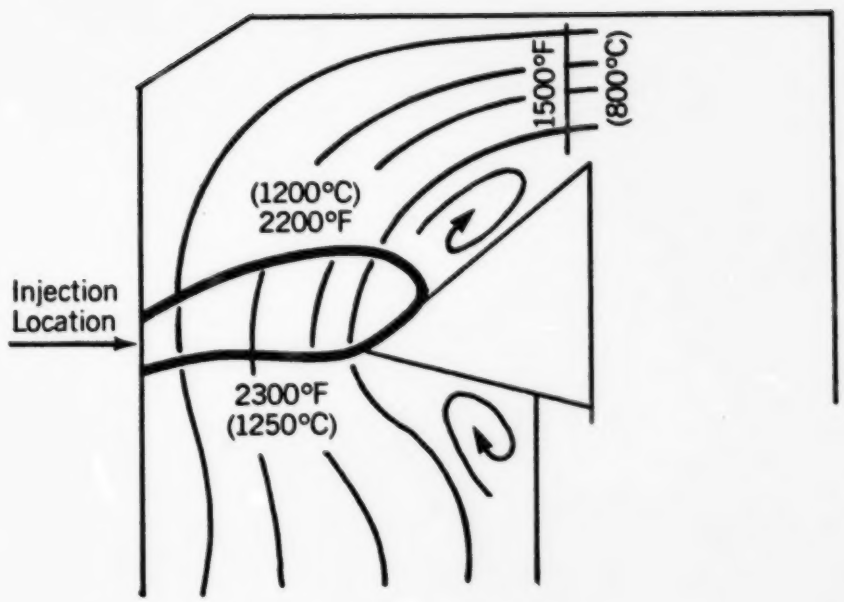

Figure 3. Location of Sulfation Temperature Window and Estimated Flow Pattern in Edgewater Boiler.

is an iterative process based on use of a combination of predictive tools and experimental investigation aimed at getting an even distribution of sorbent across a plane in the boiler. Based on boiler geometry and operating characteristics, a number of practical injection designs can be considered and refined using predictive techniques. The most promising injection combinations can then be evaluated experimentally using scaled down boiler models to select an injection scheme that will give an optimum mixing pattern in the boiler. The acrylic 1:15 scale model of the Edgewater boiler used in cold flow injection studies is shown in Figure 4.

Based on the Edgewater boiler geometry, boiler combustion air limitations, and expected injection patterns, a flexible injection scheme has been proposed which will provide the ability to inject at three levels in the boiler--at the nose level, and two levels above the nose. Only two injection levels will be operable at one time. Each level will have a row of eight injector ports on the front wall; the middle level will also have two injector ports on each side wall. Provision has been made for variable injection velocities and the ability to tilt the injectors at the two upper levels 30° down from horizontal.

BURNER SELECTION

The NO_x control component of LIMB at the Edgewater site is being implemented by replacement of the existing B&W circular burners with low-NO_x burners in which peak flame temperatures are lowered to reduce NO_x formation. A number of commercial low-NO_x burners are available, but B&W burners were preferred because of their compatability with existing burner openings and boiler peripherals. Objectives for the burner were to reduce the NO_x emissions level to approximately 129 to 172 ng NO_x/J (0.3 to 0.4 lb $NO_x/10^6$ Btu), produce a flame length of less than 6.7 m (22 ft) to avoid flame impingement on the back wall, and operate with a secondary air pressure drop of less than 1.5 kPa (6 in. of water) to avoid costly changes in existing fan equipment.

Although a B&W Dual Register Burner (DRB) is commercially available for low-NO_x emissions, there was a question about this burner's ability to operate within the restricted front-to-back-wall distance available for flame length. A 3-month screening test program, using a single burner, was conducted on EPA's Large Watertube Simulator (LWS) using the DRB and two other burners--a Babcock-Hitachi burner and a new B&W burner, designated the XCL. The Babcock-Hitachi burner, a new design now in commercial operation in Japan, is reported to produce very low NO_x emissions, while the XCL burner is aimed at emissions comparable to those achieved by the Japanese burner. All three burners were designed for 9 MW (79×10^6 Btu/hr) to match the output of a single burner in the Edgewater boiler.

The screening tests showed the difficulty of fully meeting all criteria for the Edgewater application. Table 1 summarizes representative data on these three burners. The DRB used the same throat size as the other burners which resulted in lower than standard velocities. The DRB consequently produced unusually long flames and low NO_x levels.

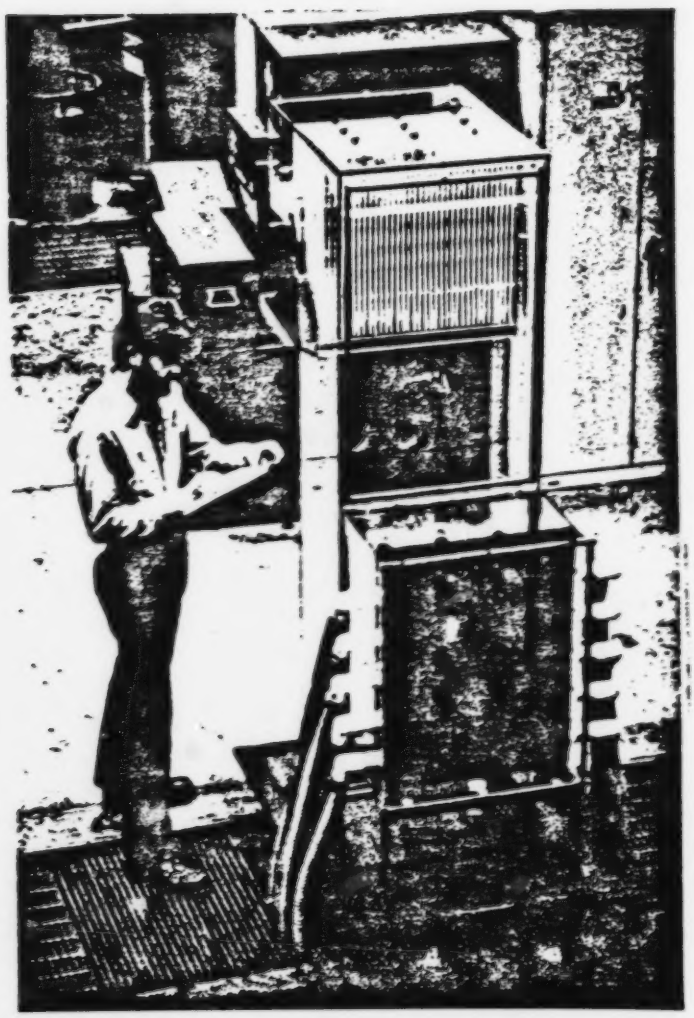

Figure 4. General View of the Edgewater Boiler Isothermal Flow Model.

The flame length criteria can be achieved by use of an impeller which markedly increases NO_x. The Hitachi burner can operate at low NO_x levels with satisfactory flame length, but the secondary air swirl required for shorter flames is achieved at the expense of high pressure drop. The XCL burner, by adjusting an impeller, can vary NO_x emissions and flame lengths at moderate pressure drops. The choice was made to proceed with the XCL burner as the burner of choice in the design.

TABLE 1. BURNER TEST RESULTS

Burner	NO_x ng/J (lb/10^6 Btu)	Flame Length m(ft)	Windbox Pressure kPa (in. H_2O)
DRB	107 (0.25)	>6.7 (>22)	1.1 (4.6)
	356 (0.83)	5.5 (18)	1.5 (6.0)
Hitachi	145 (0.34)	6.1 (20)	1.9 (7.5)
	125 (0.29)	5.8 (19)	3.3 (13.2)
XCL	126 (0.29)	>6.7 (>22)	1.4 (5.5)
	197 (0.46)	6.1 (20)	0.9 (3.5)
	231 (0.54)	4.9 (16)	1.4 (5.5)

MATERIAL HANDLING

An important aspect of the LIMB design is the specification of equipment and facilities for storage, handling, transporting, and feeding sorbent to the boiler. For the Edgewater Demonstration, it was specified that the material handling system be capable of delivering up to 9.1 metric tons/hr (10 T/hr) of sorbent to the boiler with the flexibility of handling both fine-sized hydrated lime and coarse limestone. Important considerations in the design were mechanical reliability, prevention of line and equipment pluggage, accurate feed control, and uniform distribution to the injectors.

In the proposed material handling system (Figures 5 and 6), sorbent is delivered by truck to the plant and pneumatically transferred to a ground level storage silo. The stored sorbent is transferred by compressed air to a sixth-floor-level feed silo as needed. The storage silo has an aerated bin bottom, and the feed silo has a bin vibrator to promote sorbent flow. All conveying aeration air is dried to minimize moisture in the system. From the feed silo, a controlled feed rate of sorbent is provided to each of the two injection levels in use. Each level has its own independent feed system with a weight loss differential feeder which can provide a sorbent feed rate to within $\pm$ 1% accuracy. The high elevation of the feed silo promotes smooth sorbent flow by minimizing upward and horizontal lines in the delivery system. Dried conveying air is supplied through

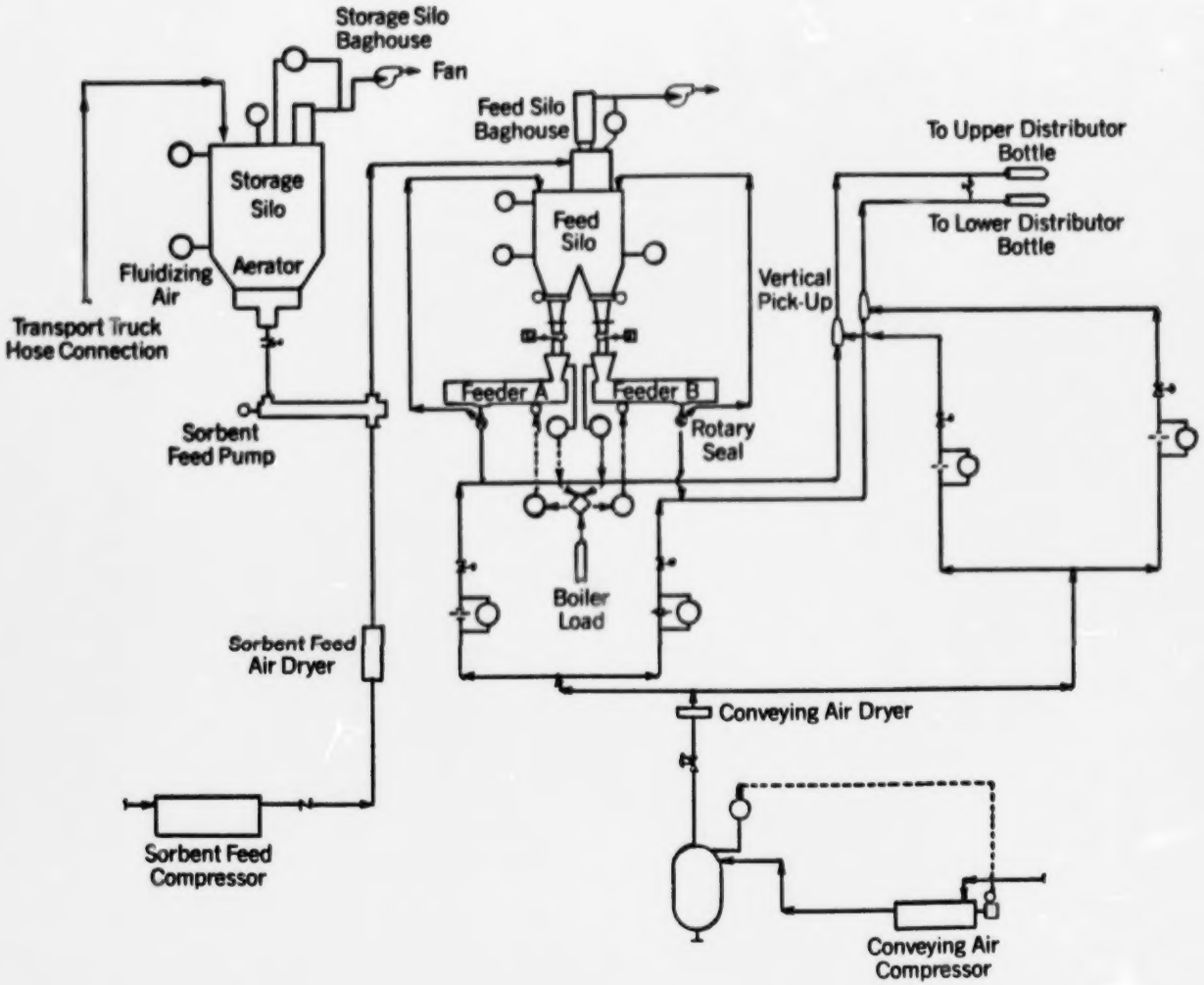

FIGURE 5. SORBENT FEED SYSTEM.

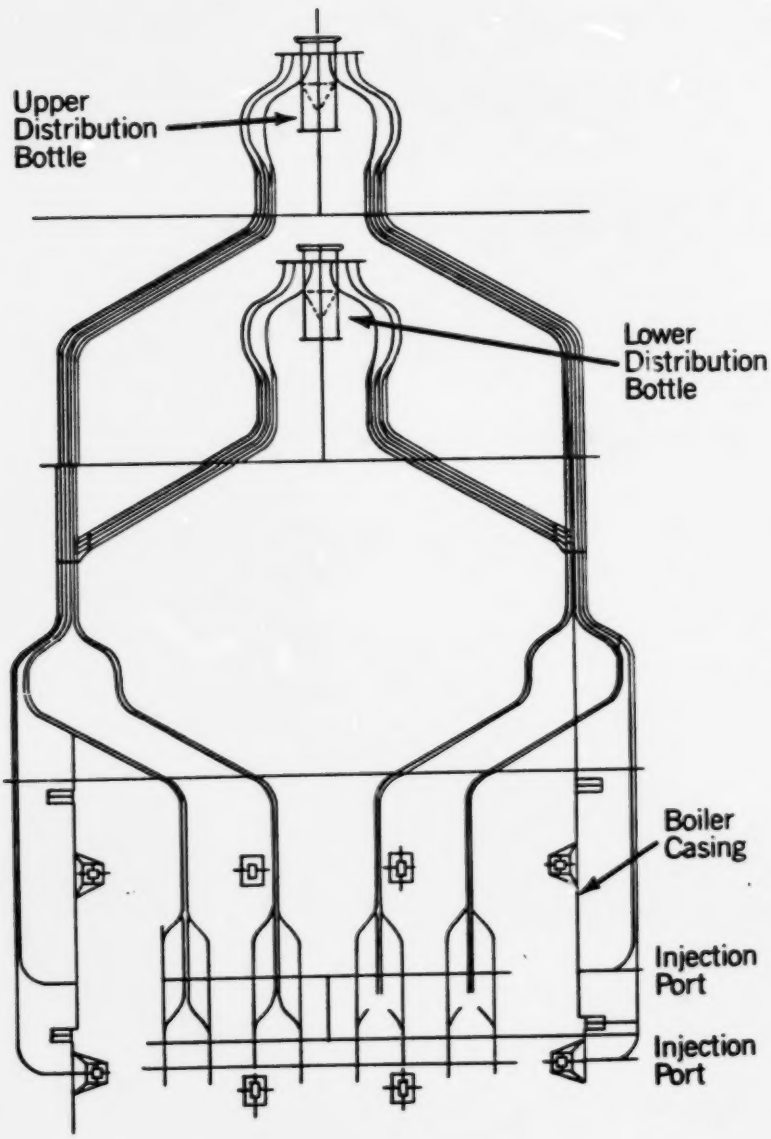

FIGURE 6. SORBENT DISTRIBUTION SYSTEM.

rotary valves to convey the sorbent to a distributor bottle for each level. The bottles distribute the mixture into the designated number of injection lines which transport the mixture to the boiler. At the boiler, a booster air fan provides injection air through the outer portion of a concentric injector nozzle to carry the sorbent into the boiler with the required penetration and dispersion.

PARTICULATE CONTROL

Although the LIMB technology is not a scheme for controlling particulate emissions, particulate control is an important consideration in all LIMB applications. In this regard, there are three concerns with the LIMB process—the loading may increase by a factor of two to three, the ash resistivity may increase by 100-fold, and the mean particle size will be lowered—all of which make particulate control more difficult. These effects are of special concern in retrofit applications where existing electrostatic precipitators (ESPs) are designed to meet applicable mass emission rate and visibility regulations without sorbent addition.

The Edgewater ESP is unique for boilers of the Edgewater vintage in that it was retrofitted to the unit in 1982 and is substantially oversized for its present duty. Estimates indicate that existing emission standards can be met even with LIMB addition with this ESP. Other boiler LIMB retrofits may, however, have to consider construction of additional ESP surface area, prechargers, and/or gas conditioning (humidification, SO_3 addition) to remain within existing emission requirements.

The test plan for the Demonstration will include a time period in which the ESP operation will be altered to simulate a marginal ESP to permit a more general assessment of the LIMB effects on the ESP. Construction and operation of the flue gas humidification system just before the ESP will also develop further information on the effects of gas conditioning.

WASTE HANDLING AND DISPOSAL

Application of LIMB creates an additional waste load and a change in ash properties. The present Edgewater waste handling and disposal system is a dry system in which ash is pneumatically removed from the ESP bottom to an ash silo, sprayed with a small amount of water in a pug mill for dust control, and trucked to a nearby landfill. In order to verify that the LIMB ash could be processed in the existing equipment, several truckloads of ash material generated during lime injection at a Canadian power plant were transported to the Edgewater plant and processed through the silo pug mill system. The Canadian material was similar to the ash expected at Edgewater, but had a slightly lower free lime content. It was found that the lime in the ash could be neutralized (hydrated) in the pug mill and a dust-free material could be produced for truck hauling to a landfill. Control of water amount and rate were found to be critical to avoid pug mill pluggage and hardening of the material in the truck.

Testing of LIMB waste under conditions specified in the Resource Conservation and Recovery Act (RCRA) showed (Table 2) that leachable toxic materials were far below levels considered to be hazardous, that rain runoff from the stored material would appear to meet required pH levels, and that ignitability and reactivity are not a problem. Current plans are for the LIMB-modified ash to be disposed of in an existing landfill but separated from conventional ash storage for observation and testing.

TABLE 2. LEACHATE DATA FOR SIMULATED LIMB DEMONSTRATION WASTE PRODUCTS

Metal	Allowable Limit Per RCRA*	Demo Coal/ Hydrate A*	Demo Coal/ Hydrate B*
Arsenic	5	0.0145	0.0210
Barium	100	4.11	4.24
Cadmium	1	0.00095	<0.0005
Chromium	5	0.0394	0.0240
Lead	5	<0.0030	0.0045
Mercury	0.2	<0.0003	<0.0003
Selenium	1	0.0296	0.0228
Silver	5	<0.0005	<0.0005
pH	12.5	(12.4/12.2)†	(12.4/12.2)†

* Concentration in extract in mg/l.

† Before/after acetic acid addition per the Extraction Procedure (EP) Toxicity Test.

An active effort is being made by EPA and others to produce a salable product from the LIMB waste, including pelletizing into a usable aggregrate, use in neutralization of acidic wastes, and recycle of unreacted sorbent back to the LIMB process, all with the aim of reducing process costs. If these techniques can be scaled up and shown to be applicable to the Edgewater conditions, they will be incorporated into the Edgewater waste control scheme.

A detailed evaluation of the waste handling and disposal system will be made during the Demonstration to ensure that any potential problems are resolved.

SUMMARY

EPA's LIMB research and development program has developed an understanding of key processes governing the control of sulfur emissions from coal-fired utility boilers with dry sorbent injection. An engineering evaluation of this information has resulted in the development of a process design for the retrofit of a LIMB system to a 105 MWe wall-fired utility boiler and a planned 1-year demonstration of system operation. The Demonstration process design is described with pertinent program results which support the choices of design variables. The project is expected to demonstrate that LIMB can achieve greater than 50% control of SO_x and NO_x emissions at a fraction of the cost of more conventional wet flue gas scrubbing systems.

ACKNOWLEDGMENTS

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